CLAIMS

What is claimed is:

1. An optical isolator including an input fiber carrying input light and an output fiber and comprising:

a birefringent walk-off plate dividing the input light into an ordinary ray sub-light and an extraordinary ray sub-light thereof, and deflecting the extraordinary ray sub-light thereof;

a reciprocally rotating optical element provided adjacent to the birefringent walk-off plate and reciprocally rotating the polarization of each of the sub-lights by 45° in a first direction;

at least one lens collimating the input light and focusing output light;

a mirror reflecting the collimated, divided, reciprocally rotated sub-lights; and

a Faraday rotator and associated magnets provided adjacent to the birefringent walk-off plate and to the reciprocally rotating optical element, non-reciprocally rotating the polarization of the sub-lights by 45° in the first direction, wherein input light received from the input fiber travels in a forward direction from the input fiber to the birefringent walk-off plate, to the reciprocally rotating optical element, to the mirror, back to the Faraday rotator, and back to the birefringent walk-off plate and the sub-lights of the forward-traveling input light are recombined by the birefringent walk-off plate into output light exiting the isolator through the output fiber, whereas input light received from the output fiber travels in a reverse direction opposite to that of the forward direction and the sub-lights thereof are deflected away from each other during each traversal of the birefringent walk-off plate.

2. The optical isolator as recited in claim 1, wherein the birefringent walk-off plate divides the reverse direction input light into an ordinary ray sub-light and an

extraordinary ray sub-light and deflects the extraordinary ray sub-light, the Faraday rotator non-reciprocally rotates the polarization of the reverse direction sub-lights by 45° in the first direction, the at least one lens collimates and directs the reverse direction sub-lights onto the mirror, which reflects them to the reciprocally rotating optical element which rotates their polarizations by 45° in the first direction, and the birefringent plate directs the reverse direction sub-lights away from entering the input fiber.

3. The optical isolator as recited in claim 1, wherein the at least one lens is disposed between the mirror and the birefringent plate and the distance from the at least one lens to the mirror is the same as the distance from the at least one lens to the far side relative to the mirror of the birefringent walk-off plate.

4. The optical isolator as recited in claim 1, wherein the optical isolator is a single stage polarization independent optical isolator.

5. The optical isolator as recited in claim 1, further comprising a ferrule including the input fiber and the output fiber.

6. The optical isolator as recited in claim 1, further comprising:

a polarization rotation compensator provided adjacent to the reciprocally rotating optical element and providing a range of polarization angles with respect to wavelength of the sub-lights input thereto.

7. The optical isolator as recited in claim 6, wherein the birefringent walk-off plate divides the reverse direction input light into an ordinary ray sub-light and an extraordinary ray sub-light and deflects the extraordinary ray sub-light, the Faraday

rotator non-reciprocally rotates the polarizations of the reverse direction sub-lights by 45° in the first direction, the at least one lens collimates and directs the reverse direction sub-lights onto the mirror, which reflects their polarizations to the polarization rotation compensator and, upon exit thereof, to the reciprocally rotating optical element which rotates them by 45° in the first direction, and the birefringent plate directs the reverse direction sub-lights away from entering the input fiber.

8. The optical isolator as recited in claim 6, wherein the at least one lens is disposed between the mirror and the distance from the at least one lens to the mirror is the same as the distance from the at least one lens to the far side relative to the mirror of the birefringent walk-off plate.

9. The optical isolator as recited in claim 6, wherein the optical isolator is a single stage broadband polarization independent optical isolator.

10. An optical isolator including an input fiber carrying input light and an output fiber and comprising:

a first birefringent walk-off plate dividing light input thereto into an ordinary ray sub-light and an extraordinary ray sub-light thereof, and deflecting the extraordinary ray sub-light thereof;

a first reciprocally rotating optical element provided adjacent to the birefringent walk-off plate and reciprocally rotating the polarization of each of the sub-lights of light input thereto by 45° in a first direction;

a second reciprocally rotating optical element provided adjacent to the birefringent walk-off plate and reciprocally rotating the polarization of each of the sub-lights of light input thereto by 45° in a second direction opposite to the first direction;

a Faraday rotator and associated magnets provided adjacent to the first reciprocally rotating optical element and to the second reciprocally rotating optical element and non-reciprocally rotating the sub-lights of light input thereto by 45° in a first direction;

a second birefringent walk-off plate deflecting the extraordinary ray of light input thereto;

at least one lens collimating light input thereto;

a mirror receiving and reflecting collimated light directed thereon by the at least one lens, wherein input light received from the input fiber travels in a forward direction from the input fiber to the first birefringent walk-off plate, to the first reciprocally rotating optical element, to the Faraday rotator, to the second birefringent walk-off plate, to the mirror, back to the second birefringent walk-off plate, back to the Faraday rotator, to the second reciprocally rotating optical element, and back to the first birefringent walk-off plate and the sub-lights of the forward-traveling input light are recombined by the first birefringent walk-off plate into output light exiting the optical isolator through the output fiber, whereas input light received from the output fiber travels in a reverse direction opposite to that of the forward direction and the sub-lights thereof are deflected away from each other during each traversal of each of the first and the second birefringent walk-off plates.

11. The optical isolator as recited in claim 10, wherein the optical isolator is a double stage polarization independent optical isolator.

12. The optical isolator as recited in claim 10, further comprising a four-fiber ferrule including the input fiber and the output fiber.

13. The optical isolator as recited in claim 10, further comprising:

polarization rotation compensators, one of which is located between the first reciprocally rotating optical element and the Faraday rotator and the other of which is located between the second reciprocally rotating optical element and the first birefringent plate, said polarization rotation compensators providing a range of polarization angles with respect to wavelength of the sub-lights input thereto.

14. The optical isolator as recited in claim 13, further comprising a ferrule including the input fiber and the output fiber.

15. An integrated single-stage polarization independent optical isolator and monitor including an input fiber carrying input light and an output fiber and comprising:

a double-stage reflection isolator transmitting light received from the input fiber in a forward direction therethrough to the output fiber and preventing transmission in a reverse direction therethrough to the output fiber of light received from the output fiber, said double-stage reflection isolator including a reflective mirror passing a portion of the input light travelling in the forward direction to pass therethrough;

a window receiving the passed input light; and

a photo-detector coupled to the window and monitoring the passed input light.

16. The integrated single-stage polarization independent optical isolator and monitor as recited in claim 15, wherein the double-stage reflection isolator comprises:

a first birefringent walk-off plate dividing light input thereto into an ordinary ray sub-light and an extraordinary ray sub-light thereof, and deflecting the extraordinary ray sub-light thereof,

a first reciprocally rotating optical element provided adjacent to the birefringent walk-off plate and reciprocally rotating the polarization of each of the sub-lights of light input thereto by 45° in a first direction,

a second reciprocally rotating optical element provided adjacent to the birefringent walk-off plate and reciprocally rotating the polarization of each of the sub-lights of light input thereto by 45° in a second direction opposite to the first direction,

a Faraday rotator and associated magnets provided adjacent to the first reciprocally rotating optical element and to the second reciprocally rotating optical element and non-reciprocally rotating the sub-lights of light input thereto by 45° in a first direction,

a second birefringent walk-off plate deflecting the extraordinary ray of light input thereto,

at least one lens collimating light input thereto, and

a mirror receiving and reflecting collimated light directed thereon by the at least one lens, wherein input light received from the input fiber travels in a forward direction from the input fiber to the first birefringent walk-off plate, to the first reciprocally rotating optical element, to the Faraday rotator, to the second birefringent walk-off plate, to the mirror, back to the second birefringent walk-off plate, back to the Faraday rotator, to the second reciprocally rotating optical element, and back to the first birefringent walk-off plate and the sub-lights of the forward-traveling input light are recombined by the first birefringent walk-off plate into output light exiting the optical isolator through the output fiber, whereas input light received from the output fiber travels in a reverse direction opposite to that of the forward direction and the sub-lights thereof are deflected away from each other during each traversal of each of the first and the second birefringent walk-off plates.

17. An optical isolator/monitor/amplifier receiving from the input fiber input light traveling in a forward propagation direction and input from the output fiber light traveling in a reverse propagation direction, said optical isolator/monitor/amplifier comprising:

a broadband single-stage reflection optical isolator transmitting light received from one of light input fibers in a forward direction therethrough to one of light output fibers and preventing transmission of light into the input fibers; and

monitor/amplifier components monitoring and amplifying the light traveling in the forward direction.

18. The optical isolator/monitor/amplifier as claimed in claim 17, wherein the broadband single-stage reflection optical isolator comprises:

at least one lens collimating the input light and focusing the output light,

a mirror reflecting the ordinary ray sub-lights and the extraordinary ray sub-lights of the input light, and

a single stage broadband polarization independent optical element dividing, deflecting, and rotating the input light such that input light entering the optical isolator/monitor/amplifier from the input fiber passes through the single stage broadband polarization independent optical element onto the mirror, and is reflected by the mirror to the single stage broadband polarization independent optical element and passes therethrough to the output fiber, whereas input light traveling in the reverse propagation direction from the output fiber is prevented from entering the input fiber by the single stage broadband polarization independent optical element.

19. The optical isolator/monitor/amplifier as recited in claim 17, further comprising a ferrule including the input fiber and the output fiber.

20. The optical isolator/monitor/amplifier as recited in claim 17, wherein the monitor/amplifier components input laser light from a co-pump laser along a first input port and from a counter-pump laser along a second input port, and monitor the light, wherein the light is prevented from entering the first input port and the second input port.

21. The optical isolator/monitor/amplifier as recited in claim 18, wherein the mirror is a partially-reflective mirror and said monitor/amplifier components receive input counter-pump laser light from a counter-pump laser and input co-pump laser light from a co-pump laser, said monitor/amplifier components comprising a birefringent walk-off plate, a first reciprocally rotating optical element, a Faraday rotator, and a second reciprocally rotating optical element which, when placed in combination with the single stage broadband polarization independent optical element, form single-stage optical isolators preventing the input co-pump laser light from travelling to the counter-pump laser and the input counter-pump laser light from travelling to the co-pump laser.

22. An optical system comprising:

an Er-doped fiber; and

an optical isolator/monitor/amplifier coupled to the Er-doped fiber, said optical isolator/monitor/amplifier comprising:

a broadband single-stage reflection optical isolator; and

a front four-fiber ferrule including a first and a second light input fiber and a first and a second light output fiber, said Er-doped fiber being coupled between the first output light fiber and the second input light fiber, said broadband single-stage reflection optical isolator transmitting light received from one of the light input fibers in a forward direction therethrough to a corresponding one of the light output fibers and preventing transmission of light in a reverse direction to the input fibers; and

monitor/amplifier components monitoring and amplifying the light traveling in the forward direction, wherein a light entering the first input light fiber travels in a forward propagation direction through the optical isolator/monitor/amplifier and is output by the first output light fiber into the Er-doped fiber, which transmits the light to the second input light fiber of the optical isolator/monitor/amplifier, which outputs the light through the second output light fiber.

23. The optical isolator/monitor/amplifier as recited in claim 22, wherein the broadband single-stage reflection optical isolator comprises:

at least one lens collimating the input light and focusing the output light,

a mirror reflecting the ordinary ray sub-lights and the extraordinary ray sub-lights of the input light, and

a single stage broadband polarization independent optical element dividing, deflecting, and rotating the input light such that input light entering the optical isolator/monitor/amplifier from the input fiber passes through the single stage broadband polarization independent optical element onto the mirror, and is reflected by the mirror to the single stage broadband polarization independent optical element and passes therethrough to the output fiber, whereas input light traveling in the reverse propagation direction from the output fiber is prevented from entering the input fiber by the single stage broadband polarization independent optical element, wherein the mirror is a partially-reflective mirror and said monitor/amplifier components receive input counter-pump laser light from a counter-pump laser and input co-pump laser light from a co-pump laser, said monitor/amplifier components comprising a birefringent walk-off plate, a first reciprocally rotating optical element, a Faraday rotator, and a second reciprocally rotating optical element which, when placed in combination with the single stage broadband polarization independent optical element, form single-stage optical

isolators preventing the input co-pump laser light from travelling to the counter-pump laser and the input counter-pump laser light from travelling to the co-pump laser.

24. An optical system comprising:

an Er-doped fiber;

a broadband double-stage polarization independent polarization-mode-dispersion-free optical isolator coupled to the Er-doped fiber and comprising a first input fiber, a second input fiber, a first output fiber, and a second output fiber; and

an optical isolator/monitor/amplifier coupled to the broadband double-stage polarization independent polarization-mode-dispersion-free optical isolator and comprising a third input fiber, a fourth input fiber, a third output fiber, and a fourth output fiber, wherein the broadband double-stage polarization independent polarization-mode-dispersion-free optical isolator and the optical isolator/monitor/amplifier are coupled sequentially to each other such that the first output fiber is coupled to the third input fiber, the third output fiber is coupled to one end of the Er-doped fiber and the fourth input fiber is coupled to the other end of the Er-doped fiber, the fourth output fiber is coupled to the second input fiber, and a light entering the first input fiber travels in a forward propagation direction from the first input fiber to the second output fiber, making two passes through each of the broadband double-stage polarization independent polarization-mode-dispersion-free optical isolator and the optical isolator/monitor/amplifier, and a light entering the optical system from any of the output fibers is prevented from entering into any of the input fibers.

25. An integrated single-stage polarization independent optical isolator/monitor transmitting light received from an input fiber in a forward direction therethrough to an output fiber and preventing transmission of light received from the output fiber in a

reverse direction therethrough to the input fiber and detecting the power of a light transmitted in the forward propagation through the optical isolator/monitor.

26. An apparatus coupled to an input fiber and to an output fiber and receiving from the input fiber input light traveling in a forward propagation direction and input from the output fiber light traveling in a reverse propagation direction, said apparatus comprising:

at least one lens collimating the input light and focusing output light;

a mirror reflecting the ordinary ray sub-lights and the extraordinary ray sub-lights of the input light; and

optical isolator means for transmitting the input light traveling in the forward direction and preventing transmission of the input light traveling in the reverse direction, said optical isolator means dividing, deflecting, and rotating the input light such that input light entering the apparatus from the input fiber passes through the optical isolator means to the mirror, and is reflected by the mirror to the optical isolator means and passes therethrough to the output fiber, whereas input light traveling in the reverse propagation direction from the output fiber is prevented from entering the input fiber by the optical isolator means.

27. The optical isolator as recited in claim 1, wherein the reciprocally rotating optical element includes a $\lambda/2$ plate.

28. The optical isolator as recited in claim 10, wherein the first reciprocally rotating optical element includes a $\lambda/2$ plate and the second reciprocally rotating optical element includes a $\lambda/2$ plate.

29. The integrated single-stage polarization independent optical isolator and monitor as recited in claim 16, wherein the first reciprocally rotating optical element includes a $\lambda/2$ plate and the second reciprocally rotating optical element includes a $\lambda/2$ plate.

30. The optical isolator/monitor/amplifier as recited in claim 21, wherein the first reciprocally rotating optical element includes a $\lambda/2$ plate and the second reciprocally rotating optical element includes a $\lambda/2$ plate.

31. The optical isolator/monitor/amplifier as recited in claim 23, wherein the first reciprocally rotating optical element includes a $\lambda/2$ plate and the second reciprocally rotating optical element includes a $\lambda/2$ plate.

32. The integrated single-stage polarization independent optical isolator as recited in claim 15, further comprising a rear lens collimating the portion of the passed input light.

33. The optical system as recited in claim 22, wherein the optical isolator/monitor/amplifier further comprises rear ports including two input ports and two output ports.